Wyle Report

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NIGHTTIME NOISE CRITERIA AND LAND-USE GUIDELINES FOR THE CITY OF HIGH POINT

Prepared For

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Executive Summary

The goal of the current Federal Aviation Administration (FAA) noise compatibility guidelines is to provide guidance that encourages appropriate land uses around all U.S. airports. The FAA guidelines specify the Day-Night Average Sound Level (termed L_{dn} or DNL) as the noise metric of choice in defining land-use compatibility. Based on this guidance, many Federal Aviation Regulation Part 150 Noise Compatibility Studies and Environmental Assessments and Environmental Impact Statements that have been conducted at U.S. airports are based upon the DNL 65 dB contour to identify the boundary between compatible or noncompatible noise exposure levels for noise-sensitive land uses. In essence, most of these studies have deferred to the DNL 65 dB threshold as a rigid standard or a de-facto "line in the sand"; and the general consensus has been that noise-sensitive land use without restriction should be allowed for areas that are exposed to noise levels below DNL 65 dB.

The Piedmont Triad International Airport (PTIA) is scheduled to become a new, full-service air cargo hub for FedEx in the near future. The City of High Point (City) is concerned that with the increase in nighttime operations, defining land-use compatibility by the projected DNL 65 dB contour will not be sufficient to protect the community from the increase in nighttime noise exposure. The new cargo operations forecast indicates that there will be a substantial increase in the number of nighttime operations. Since DNL is a 24-hour average noise metric (with a 10-dB weighting factor added to each operation between 10 PM and 7 AM), the City is concerned that when nighttime noise levels peak, the potential for increased sleep disturbance might not be accurately portrayed by the DNL noise metric alone. The City retained Wyle Laboratories Acoustics Group (Wyle) to carefully and fully consider these issues by analyzing the projected noise impacts with the appropriate supplemental noise metrics, and to recommend noise overlay zones that will provide sufficient protection balanced with development goals in the affected areas. This reports focuses on the following questions:

- Is DNL the appropriate metric for all land-use guidelines?
- What additional metrics are more appropriate for the specific circumstances?
- What are the criteria for delineating land-use zones?
- What are the appropriate control measures for each of these zones?

The FAA's DNL 65 dB guideline does not fully portray the nighttime noise environment in every situation, even with the 10 dB weighting factor for nighttime operations. Wyle has found that supplemental noise metrics that quantify noise levels from individual aircraft over-flights and frequency of operations are better indicators of the degree of interference with human activities, particularly during time periods less than a full 24-hour day. Sleep and speech are the human activities most interfered with by aircraft noise. Wyle believes that the best metric to characterize the noise environment is the Number of Events (z)

Above a threshold noise level (x) (NAx(z)). The threshold noise level (x) is based on research studies and is expressed in terms of the Sound Exposure Level (SEL) sound level. SEL is a composite metric that represents both the intensity and duration of a noise event, and is used extensively by sleep disturbance researchers. By combining the noise level and number of events in the formula NAx(z), noise contours can be produced based on the threshold single event noise levels and number of events associated with various levels of sleep disturbance.

Based on a review of the sleep disturbance literature, Wyle has identified three areas where different zoning guidelines should be applied to provide future protection against sleep disturbance. These zoning recommendations are based on NAx(z) contours derived from varying degrees of sleep disturbance identified in research reports. Three noise overlay zones are recommended:

- Overlay Zone 3 - based on the NA80(5) contour, within which disclosure of the nighttime noise exposure level is recommended when a new residence is constructed or an existing residence is sold.

- Overlay Zone 2 - based on the NA85(2) contour, within which grant of avigation easements, a requirement for sufficient sound insulation to attain a noise level reduction of at least 25 dB in residential structures and noise disclosure are recommended.

- Overlay Zone 1 - based on the NA90(1) contour within which prohibition of new residential development and noise disclosure are recommended.

A special Overlay Zone 1A within Zone 1 is also recommended to allow further residential development with certain restrictions in a current residential area that is not suited for any other type of development.

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1.0 Introduction

The City has retained Wyle Laboratories to assess potential nighttime noise impact from the Piedmont Triad International Airport (PTIA) and develop zoning recommendations designed to protect citizens from excessive nighttime noise exposure levels. The City is located to the Southwest of PTIA and may face a significant increase in nighttime over-flights from a new air cargo operator establishing a hub at PTIA. The City is of the opinion that the land-use guidelines as recommended by the FAA, indicating compatible versus noncompatible land-use based on a "Day-Night" Average Sound Level (DNL) of 65 dB, may not protect citizens from excessive levels of nighttime noise. The concern is, that as a 24-hour average noise metric, DNL might not adequately account for the projected high number of nighttime operations within short periods associated with the new cargo hub operations. The operations scenario analyzed in this Report is the 2019 case from the 2001 Final Environmental Impact Study for PTIA.

In order to aid the City in determining appropriate noise metrics, land-use guidelines and criteria, a review of past research and published recommendations is provided. The findings and conclusions from sleep disturbance research were applied to the High Point future nighttime airport noise scenario, resulting in proposed land-use zones and zoning guidelines designed to provide sufficient protection to area residents. Some familiarity with noise metrics is necessary to understand the technical analysis and recommendations in this report. To serve that purpose, Section 2 contains a discussion of the noise metrics used. Section 3 discusses the effects of aircraft noise and the most widely accepted noise descriptors. It also provides an overview of sleep disturbance research and presents the noise criteria on which the overlay zoning districts near the airport are based. The recommended noise overlay districts are presented in Section 4. Appendix A provides a more detailed discussion than Section 2 of noise and its characteristics. Finally, Appendix B provides an in-depth look at the derivation the DNL 65 dB land-use compatibility guidelines and a detailed discussion of the latest research on sleep disturbance and interference with other human activity.

It is important to note that the only established and widely accepted guideline for nighttime aircraft noise exposure is contained in the Day/Night Average Sound Level (DNL) metric, which counts each nighttime operation between 10 PM and 7AM as 10 operations. This "penalty" increases the size of the DNL contours around an airport by a much greater degree when new operations are added at nighttime versus daytime, but DNL may not take into account the full effect of individual nighttime noise events. Since the primary concern is nighttime noise in this report, Wyle has ventured into new territory by recommending that the number of events above specific sound exposure level thresholds, rather than DNL, be used to define the land use zoning boundaries.

Research into sleep disturbance from nighttime noise events has been the subject of some major updates in the last decade, as more has become known about the effects on people in their own homes rather than as measured in the laboratory. There is some lack of consistency in the research methods used to study these effects, and there is no general consensus in the scientific community on an appropriate dose-response relationship. Moreover, researchers present findings and conclusions, but rarely offer policy recommendations. In our extensive review of the sleep disturbance research literature, Wyle has found no recommendations for limiting exposure at any particular noise level. Such decisions ultimately rest with those local officials charged with making policy decisions, and they generally rely on advice and recommendations from their staff and consultants. To this end, Wyle has carefully translated and applied the sleep disturbance results to the stated goal of the City, which is to define an appropriate balance between protecting citizens from nighttime noise exposure and development interests/objectives in exposed areas. The recommendations in this report reflect Wyle's best judgment regarding the levels that will most effectively achieve the City's stated goal. The recommended zoning criteria are not intended to establish standards or guidelines for any other community.

2.0 Noise Metrics

A noise metric is any unit of measure used to quantify or describe individual or cumulative noise events. Noise metrics used in this report are explained in Sections 2.1 – 2.4 below. Appendix A provides an in-depth discussion of noise metrics.

2.1 Maximum Sound Level

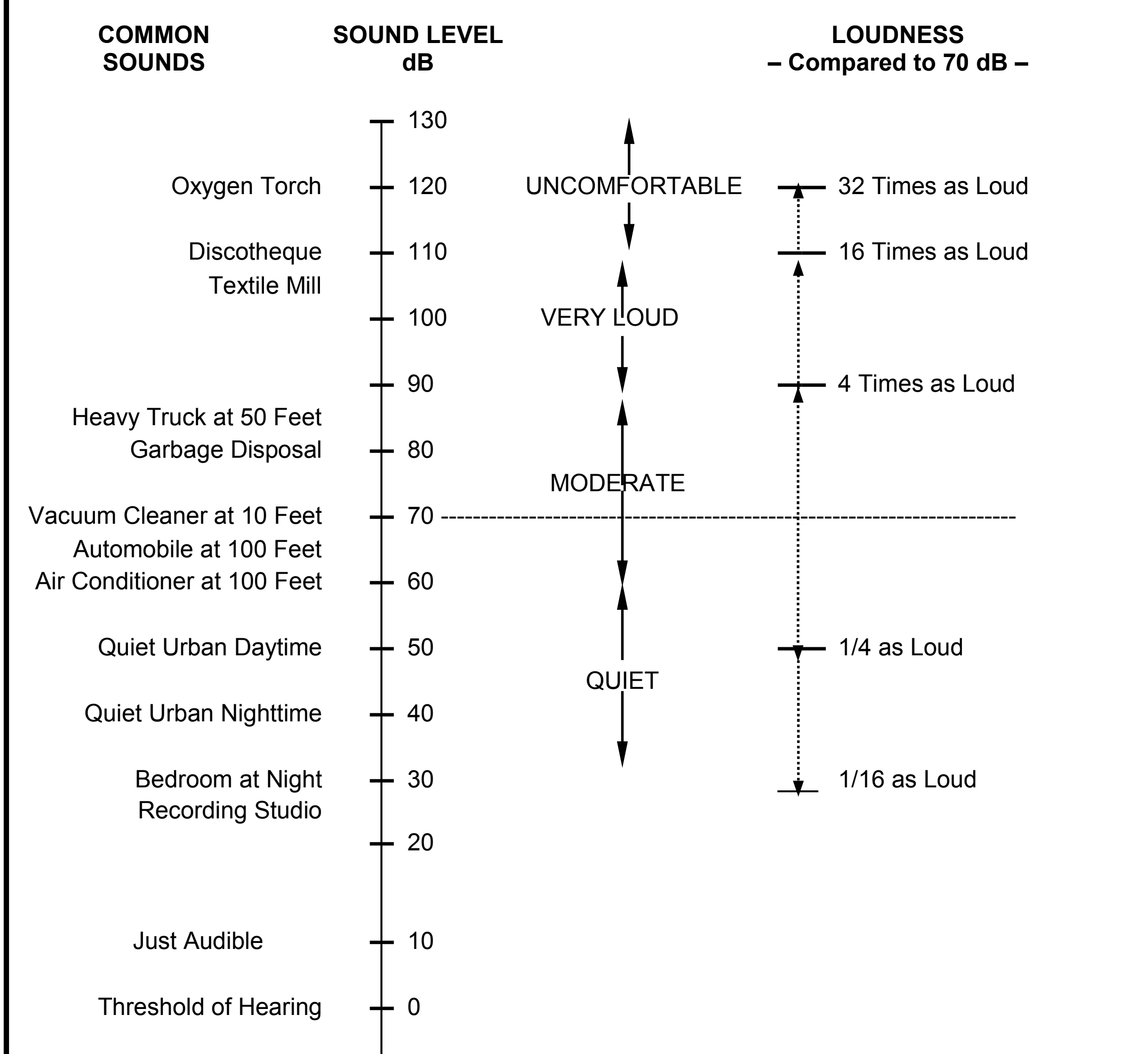
Maximum Sound Level (L_{max}) is the highest level measured during a single noise event. The L_{max} levels of typical noise events are shown in Figure 2-1. When the L_{max} of a noise event exceeds the level of conversation or the level of the TV or radio, interference results for the period of time that the L_{max} of the noise event exceeds the level of the conversation or other desired sound source, generally resulting in annoyance.

L_{max} describes the maximum level of a noise event, but does not take into account the duration. An event with a relatively low L_{max} but a longer duration can be just as intrusive as a short duration event with a higher L_{max}. In order to accurately describe a noise environment, both the L_{max} and the duration of the events must be considered. The single-event metric that combines both of these characteristics is discussed in the next section.

2.2 Sound Exposure Level

Sound Exposure Level (abbreviated SEL) is a logarithmic measure of the total acoustic energy transmitted to the listener during the noise event. Mathematically, it represents the level of a constant sound that would, in one second, generate the same acoustic energy as the actual time-varying noise event. SEL does not directly represent the sound level heard at any given time, but rather provides a measure of the net sound energy of the entire acoustic event. Since aircraft over-flights usually last longer than one second, the SEL of an over-flight is greater than the L_{max} of the over-flight.

The relationship between L_{max} and SEL is explained below. Figure 2-2 provides an illustration of the L_{max} of three sound events. Each stack of cubes represents the total sound energy for the sound event. The width of the base of the stack represents the total duration of the noise event, and the peak of each stack represents the L_{max} of the event. Event 1 has a higher L_{max} than event 2, but the same as event 3. Event 1 with duration of 5 seconds is 1 second shorter than event 2, and twice as long as event 3.



Source: Handbook of Noise Control, C.M. Harris, Editor, McGraw-Hill Book Co., 1979.

Figure 2-1. Typical A-Weighted Sound Levels of Common Sounds

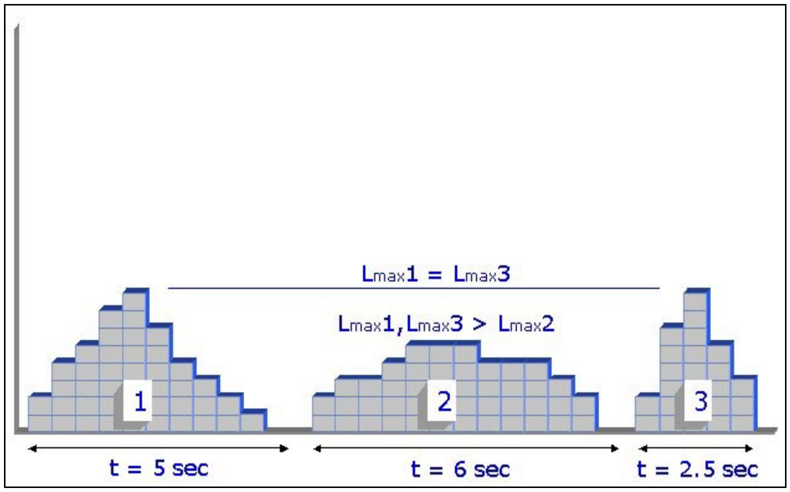


Figure 2-2. L_{max} of Three Different Noise Events

The SEL of each of these events is illustrated in Figure 2-3, where the same number of cubes are stacked on top of each other so that the base of the stack represent a one second period (2 cubes wide). The SELs of events 1 and 2 are equal, and higher than event 3.

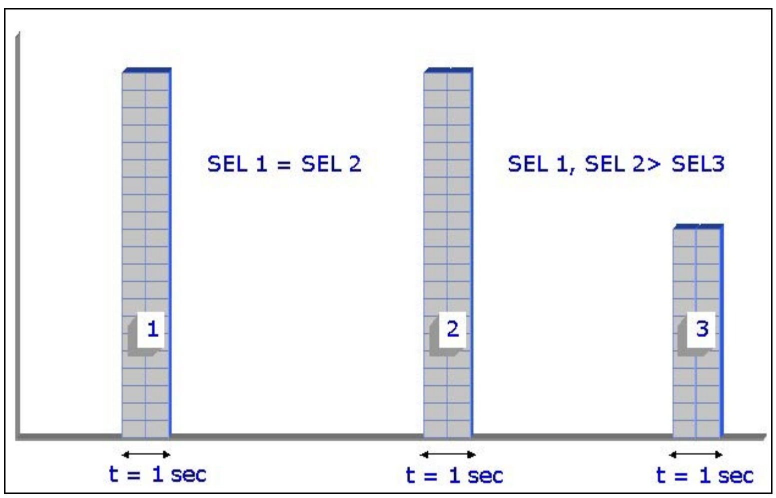


Figure 2-3. SEL of Three Noise Events
(Corresponds to the Events in Figure 2-2)

As shown above, SEL is a composite metric, which represents both the intensity of a sound and its duration, whereas L_{max} only describes the maximum noise level. Even though the L_{max} of events 1 and 3 are equal, the SEL of event 1 is higher, because the duration is greater. Similarly, event 1 has a higher L_{max} than event 2 but a shorter duration, and hence an equal SEL. This example also illustrates the need to calculate the SELs of individual events in order to compare them or to add them together to average multi-events over a period of time. This is the process utilized by the Integrated Noise Model (INM) to calculate DNL.

2.3 Day-Night Average Sound Level

The Day-Night Average Sound Level (abbreviated DNL or L_{dn}) is the most widely accepted metric for evaluation of community noise exposure from transportation sources, and is the primary metric prescribed in the Federal Aviation Regulations to describe aircraft noise exposure. DNL averages aircraft noise levels over a 24-hour period, with a 10-decibel weighting factor added to those noise events that take place between 10:00 p.m. and 7:00 a.m. The 10-decibel "penalty" accounts for the added intrusiveness of noise events that occur during normal sleeping hours. Also, nighttime ambient sound levels are typically about 10 dB lower than daytime levels.

DNL provides a single measure of overall sound exposure for a 24-hour period, but does not provide specific information on the total number of noise events or the magnitude of individual noise events. Because DNL is a cumulative average metric, a 24-hour level of 65 dB from aircraft noise events might consist of a few very noisy events or a large number of quieter events. Since sleep disturbance is related to individual noise events, nighttime noise effects are best described by single-event rather than cumulative metrics.

2.4 Number-of-Events Above

Number-of-events Above (NA) is a noise metric that shows the average number of times noise exceeds the threshold level during a specified time period, such as a day (24-hours), or night (9-hours). The results of NA analysis are displayed as map contours with each contour showing the average number of expected events above the threshold decibel level during the selected time period.

NA contours can be depicted at any noise threshold level (x) and any user defined number of events (z), notated 'NAx(z)' meaning 'z' events above noise level 'x'. These analysis parameters (x and z) may differ in each affected community, based on specific circumstances. No national standards or guidelines have yet been established for NA analyses, but under FAA regulations, each jurisdiction is free to establish its own local noise standards. The NA metric provides for much flexibility and can be tailored to any noise environment. Not only is it very descriptive, it is also highly sensitive to any changes in operating conditions. The NA contours provide an accurate model of actual noise levels experienced in affected areas of the community.

3.0 Effects of Noise on Sleep

Disturbance of sleep is a major concern in the assessment of environmental noise levels because a good night's sleep is essential to health and well-being. Physiological effects, such as increased blood pressure and heart rate, can result from exposure to noise during sleep. However, the major manifestations of sleep disturbance due to noise are a delay in the onset of sleep, a change in the depth of sleep (from one stage to another), and at the extreme, actual awakening.

3.1 Sleep Disturbance Factors

The relationship between individual aircraft noise levels and the magnitude of any effects are rather complex because the disturbance caused by an intruding sound may depend on the background noise level, the depth of sleep, previous exposure (acclamation) to aircraft noise, familiarity with the surroundings, the physiological and psychological condition of the recipient, and a host of other situational factors. The most readily measurable effect of noise on a sleeping person is the number of arousals or awakenings, and these are the effects for which current relationships are based.

3.2 Sleep Disturbance Research

The effect of intermittent noise (i.e. aircraft over-flights) on sleep is best described in terms of the SEL or the L_{max} of individual events. Since the early 1960s, a number of studies have attempted to quantify the noise levels that interfere with sleep. Initially, field studies conducted with people in their normal living situations were scarce, and so, much of the data on the impact of noise exposure on sleep originated primarily from experimental research in controlled laboratory environments. Until the late 1980s and early 1990s, the results of these laboratory experiments were used as a benchmark for establishing acceptable noise levels with the least amount of sleep disturbance

It was noted in related research that the controlled laboratory studies did not account for many factors that are important when analyzing sleep behavior, such as habituation to the environment, previous exposure to noise, awakenings from sources other than aircraft noise, etc. In the early 1990s, field studies were conducted to validate the earlier laboratory work. The most significant finding from these studies was that an estimated 80 to 90 percent of sleep disturbances were not related to individual outdoor noise events, but were instead the result of indoor noises and other non-noise-related factors (Reyner & Horne, 1995). Moreover, it was found that there was a distinctly lower effect of noise on sleep in real-life conditions than had been previously reported from laboratory studies

(Ollerhead 1992, Pearsons 1995). Other studies indicated that for a good sleep, not only the noise level but also the number of occurrences plays a role.

Appendix B provides a literature review of the most prominent sleep disturbance studies that have been conducted worldwide. The results of these studies were used for the compilation of the land-use zones discussed in the next Section.

3.3 Development of Sleep Criteria

Based on a review of the sleep disturbance literature summarized in Appendix B, Wyle used the Number-of-events Above (NA) metric to establish the criteria that will be used to identify land-use zones for The City. As explained earlier, NA takes into account the single event level and number of events for a specified period of time, in this case the period between 10 p.m. and 7 a.m. (nighttime). It has been well established in the scientific community that SEL measures sleep disturbance much more reliably than just the maximum sound level. Thus, the single event level component of the NA criteria applied here is in terms of SEL.

The NA criteria presented below were selected to minimize sleep disturbance for the majority of the population. Using NA as the metric of choice to establish land-use zones allows the City to address the airport noise environment in terms of single event levels and number of operations, rather than a time average metric such as DNL. By adopting several zones with a range of land-use restrictions, the City can define an area that is not compatible with the projected nighttime noise exposure and buffer areas where residential development is considered compatible, but only with certain restrictions imposed.

The threshold levels and number of operations for each of the three overlay zones identified below were derived from in-depth analyses of existing sleep research studies. They are:

- Zone 1 Criteria - NA90(1) contour (One event per night above SEL 90 dB)
- Zone 2 Criteria - NA85(2) contour (Two events per night above SEL 85 dB)
- Zone 3 Criteria - NA80(5) contour (Five events per night above SEL 80 dB)

These proposed overlay zone criteria are defined by the three noise contours illustrated in Figure 3-1, which are based on the 2001 Final Environmental Impact Statement's (FEIS) 2019 modeled forecast conditions for PTIA. This scenario includes the largest number of forecast nighttime operations as a result of the new FedEx cargo hub at PTIA. Using the parameters included in this 2019 forecast study allows for the farthest available look into the future airport noise environment for the City.

The proposed Zone 1, 2, and 3 Criteria are expressed in outdoor SEL and the associated number of operations per night. At each of the criteria threshold levels, the research reports predict a percentage of the exposed population who will experience sleep disturbance. This includes delaying the onset of sleep, changes in the depth of sleep (from one stage to another), and at most, actual awakenings.

The three zoning criteria were derived from data usually provided in terms of indoor SELs, as reflected in the sleep research studies. The noise models used to generate noise exposure contours generate noise levels as would be experienced outdoors. Therefore the translation between indoor and outdoor noise levels has been taken into account. Generally, the noise level reduction of a residence with windows open is about 15 dB and 20 to 25 dB with windows closed. All the criteria discussed in this report are based on a windows-open indoor to outdoor noise level reduction of 15 dB. For example, an aircraft event that registers 70 dB outdoors will be experienced at approximately 55 dB indoors if the windows are open. In the event the windows are closed, this same event will measure approximately 45-50 dB indoors. Using the worst case windows-open analysis approach projects a quality of life concern, because it does not set a local standard that requires everyone to keep the windows closed at all times. Thus, it includes flexibility for residents who are more noise sensitive to close their windows to gain a 5-10 dB noise level reduction. Also some additional sound attenuation from shielding will be experienced with open windows in bedrooms facing away from aircraft flight paths compared to bedrooms facing flight paths.

3.3.1 Derivation of Zone 1 Criteria

The Zone 1 criteria is defined by the NA90(1) contour line, and encompasses the area in which one or more events above SEL 90 dB will occur during an average night based on the 2019 forecast conditions. This criterion was derived primarily from an extensive field study in the U.K. by Ollerhead (see Appendix B), who found that minimal impact was identified for an outdoor SEL of 90 dB. This study concluded there is a 3 percent chance of some level of arousal and a 1 percent chance of brief awakenings when aircraft flyovers exceed SEL 90 dB. In addition to Ollerhead's findings, both Fidell's curve (illustrated in Figure 2-2 of Appendix B) and the 1997 Federal Interagency Committee on Aircraft Noise Report curve, that represents the average of the field study data points, show that there is a 3 percent chance of some level of sleep disturbance with noise events at SEL 90 dB.

The number of allowable events for an SEL of 90 dB has been derived from a relationship published by Miedema between sleep disturbance and average outdoor noise levels (L_{night}) in terms of percent "Highly Sleep Disturbed (%HSD), 'Sleep Disturbed (%SD), and 'Little Sleep Disturbed' (%LSD). Using this relationship, together with the relationship between L_{night}, SEL, and number of events as presented in Appendix B, a low percentage of persons exposed to less than one event per night below 90 dB SEL may experience sleep disturbance.

3.3.2 Derivation of Zone 2 Criteria

The Zone 2 criteria is defined by the NA85(2) contour line, that encompasses the area within which 2 or more events per night may occur at SEL 85 dB or greater under the forecast 2019 conditions. The SEL criterion for Zone 2 is based primarily on Fidell's curve (illustrated in Figure 2-2 of Appendix B), which indicates 2.5% awakenings on average in the exposed population at an outdoor SEL of 85 dB. As previously stated, the frequency of occurrence plays a role in sleep disturbance as well as the intrusiveness of each noise event. The number of events criterion for Zone 2 is derived primarily from Miedema's relationship between average sound level, individual sound level, and number of events, which indicates that three or less events per night at or below SEL 85 dB results in a low percentage of the population experiencing some sleep disturbance.

It is noted that the noise model input is usually based on operational data collected over a one-year period, which is then divided (by 365 days) to derive average daily operational statistics. Using the daily operational values ignores unusual busy or slow days. To account for unpredictable fluctuations in day-to-day operational variables, such as daily aircraft traffic levels, flight track utilization, and other less significant variables, the acceptable number of events at or above 85 dB SEL was adjusted down to 2 per night. Additionally, since Miedema's %HSD from aircraft noise was estimated (see Appendix B), it is appropriate to allow some margin for error and lower the number of operations for Criteria 2. Therefore, Wyle recommends that only one-half the events indicated through Miedema's relationships be applied. Since this would result in a non-integral number (1.5), Wyle recommends rounding up to the whole number of 2 events for the Zone 2 criteria.

3.3.3 Derivation of Zone 3 Criteria

The Zone 3 criteria is defined by the NA80(5) contour line that encompasses the area within which 5 or more events per night may occur at a SEL of 80 dB or higher under the forecast 2019 conditions. Based on Fidell's curve, which is illustrated in Figure 2-2 of Appendix B, an SEL of 65 dB indoors (equal to 80 dB outdoors, windows open), may result in a 2 percent chance of some level of sleep disturbance. Similar to the number of events derivation discussed in Section 3.3.2, Miedema's relationship between average sound level, individual sound level, and number of events was again used to identify that 10 events or less per night at an outdoor SEL of 80 dB, will not generate significant sleep disturbance effects. To account for some variables also discussed in Section 3.3.2, Wyle recommends that only half the events indicated through Miedema's relationships be applied, resulting in a criteria of NA80(5), to identify the Zone 3 area.

The relationship of the NA contours, using the SEL noise metric, and the projected 2019 DNL contours from the EIS are shown in Figure 3-1 below:

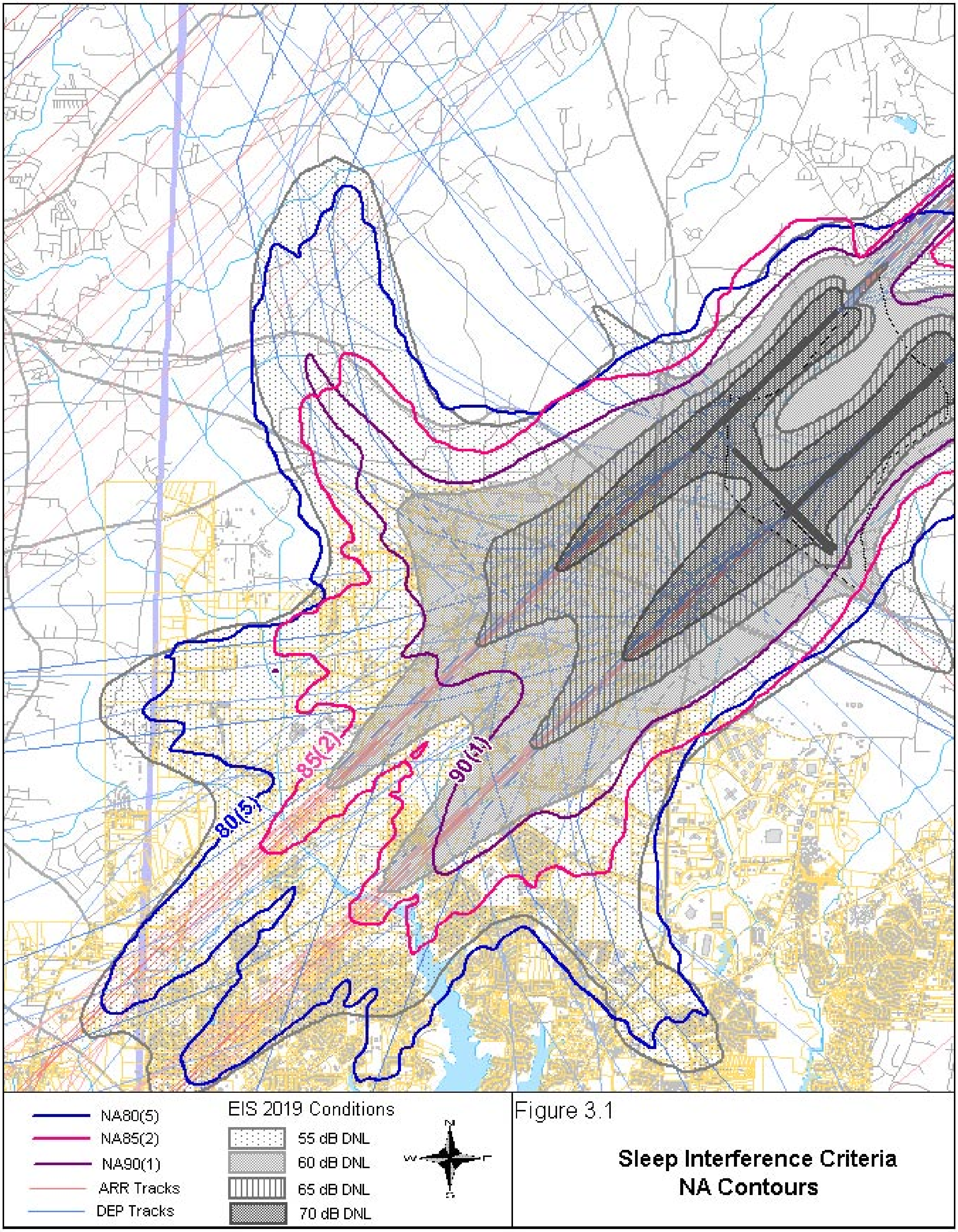


Figure 3.1

Sleep Interference Criteria NA Contours

4.0 Recommended Zoning Measures

Since the NA noise metric is more closely associated with sleep disturbance research studies than the DNL metric, Wyle recommends the use of the NA contours to implement the land-use zoning measures recommended in this section. Based on the sleep criteria discussed in Section 3.0 above, specific mitigation measures are recommended within each overlay zone. The recommended overlay zone boundaries were derived from outlining physical features of the land (i.e. streams, roads, railroads, current parcel boundaries, etc.) that enclose the respective NA noise exposure contours. This facilitates implementation and should minimize controversy over the boundaries. The proposed overlay zones are numbered in descending order from the highest exposure area, Zone 1, to the lowest exposure area, Zone 3 (which is the zone most distant from the PTIA and covers a larger area than the closer in zones).

4.1 Overlay Zone 3 – Disclosure of Noise Exposure Level

Proposed Overlay Zone 3 is encompassed by the NA80(5) contour. The number of events in the criterion for this zone is higher because the SEL of each event is lower than in Overlay Zones 1 and 2. An outdoor SEL of 80 dB equates to roughly an indoor (windows open) SEL of 65 dB and L_{max} of 55 dB. With windows closed these indoor levels would be approximately SEL 55 and L_{max} 45 dB. Research reports suggest that less than 2 percent of the population may experience some sleep disturbance from 5 events per night at an outdoor SEL of 85 dB.

Wyle recommends that within the proposed Overlay Zone 3 formal written disclosure of over-flight noise exposure levels be required as a part of all real estate transfer transactions, regardless of the underlying land use.

Figure 4-1 depicts the recommended boundary of Overlay Zone 3.

4.2 Overlay Zone 2 – Easements and Building Standards

Overlay Zone 2 is encompassed by the NA85(2) contour, and includes the area within which research reports suggest that approximately 2.5 percent of the population may experience some sleep disturbance at an outdoor SEL of 85 dB. Two events per night at this level is the threshold where sleep disturbance will likely start to become an issue if not appropriately addressed. The NA85(2) criteria was established based on an indoor SEL of 70 dB, at which 2.5 percent of the population might experience sleep disturbance. The criteria is based on a windows-open condition where any resident whose sleep is disturbed by over-flight noise with their windows open can obtain an instant noise level reduction of approximately 5-10 dB by closing all windows and doors. At this

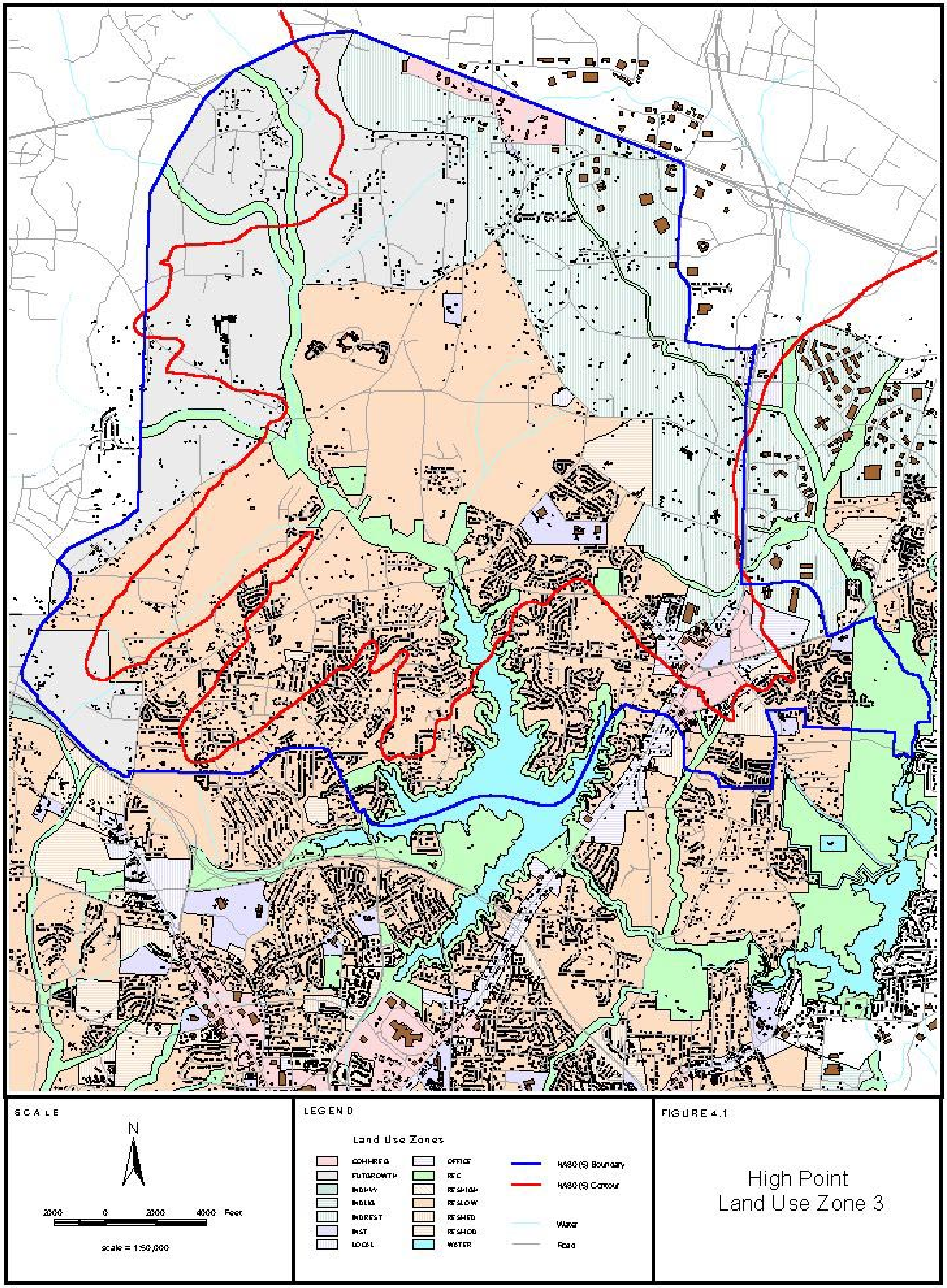


FIGURE 4.1

High Point
Land Use Zone 3

lower indoor exposure level with closed windows and doors, about one percent of the population is likely to experience sleep disturbance.

The primary measure recommended to address nighttime over-flight noise within Overlay Zone 2 is to require landowners and developers to grant avigation easements for new residential development. An avigation easement is an interest in the real property that attaches to the title of the parcel. By granting an avigation easement, the property owner formally authorizes the normal operation of aircraft to and from PTIA over their property. Avigation easements do not normally grant the right for unlimited growth in airport operations, but they can greatly reduce the potential for litigation when noise exposure remains relatively stable over time. Avigation easements also insure disclosure of noise exposure levels to future owners.

Additional measures recommended for Overlay Zone 2 are a requirement that new noise sensitive development achieve an outside to inside noise level reduction of at least 25 dB and to require sufficient ventilation and central air conditioning to allow for windows closed conditions year round. (Window or wall air-conditioning units are not advised because they require an open window or wall opening for installation). As in Overlay Zone 3, Wyle also recommends that within the Overlay Zone 2 formal written disclosure of over-flight noise exposure levels be required as a part of all real estate transfer transactions, regardless of the underlying land use.

Figure 4-2 below depicts the proposed boundary of Overlay Zone 2.

4.3 Overlay Zone 1 – No New Residential Development

Overlay Zone 1 is encompassed by the NA90(1) contour and encompasses the area within which research reports suggest that more than 3 percent of the population will likely experience sleep disturbance on any given night due to aircraft over-flights (not necessarily the same 3 percent each night). Further into this zone (closer to PTIA) the noise events will be louder and more frequent, and a higher percentage of the population will experience significant disturbance of sleep.

Since there is currently little residential development in this zone, an ideal opportunity exists to prevent future noncompatible development. Wyle strongly recommends adoption of Overlay Zone 1, within which new residential development would not be permitted.

The recommended boundary for Zone 1 is based on the assumption that many residents will sleep with open windows when weather permits. Persons currently residing in Zone 1 can achieve additional noise reduction of approximately 5-10 dB by closing all windows in their residence. Current Zone 1 residents will not be highly impacted by nighttime noise until the cargo hub project is completed and night operations start to increase. If at that time some Zone 1 residents cannot close their windows at night because they lack air conditioning,

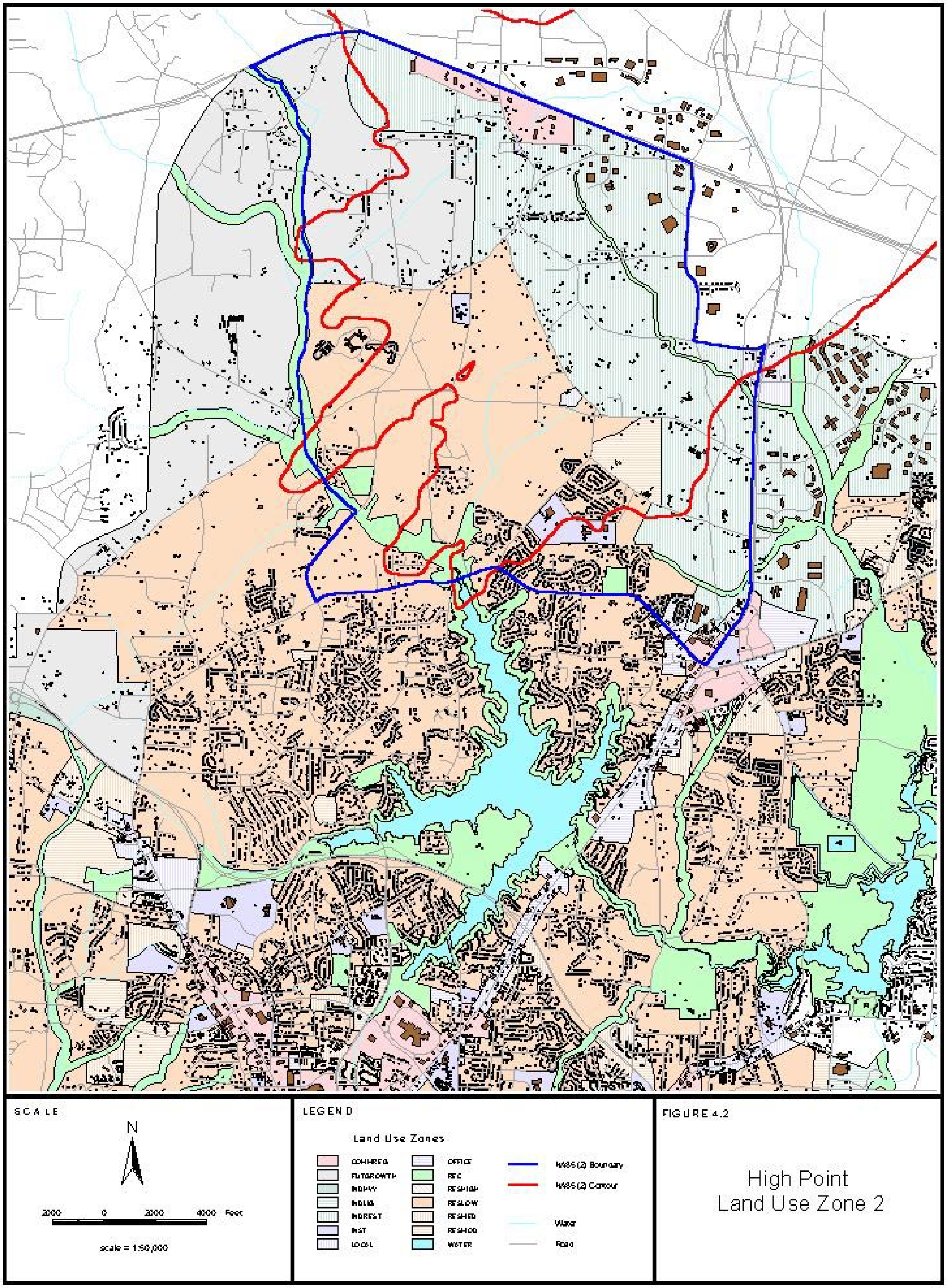


FIGURE 4.2

High Point
Land Use Zone 2

that problem can be addressed through a Federal Aviation Regulations Part 150 Noise Compatibility Study (NCP). A Federally funded measure can be included to provide air conditioning to these residents so they can close their windows year round and achieve the additional 5-10 dB noise level reduction. If any other mitigation measures are also needed at that time, they would also be addressed in the Part 150 NCP. The City should also consider immediately requiring that building permits for all living area additions to existing dwellings in Zone 1 be conditioned on a requirement for sound insulation sufficient to achieve a noise level reduction of at least 30 dB in the added space. Wyle also recommends that within Overlay Zone 1 formal written disclosure of over-flight noise exposure levels be required as a part of all real estate transfer transactions, regardless of the underlying land use.

Figure 4-3 below depicts the boundary of Zone 1.

4.4 Overlay Zone 1A – New Residential Development Permitted With Restrictions

Within proposed Overlay Zone 1 is a special area designated as Overlay Zone 1A, which is located between the dashed and solid blue lines shown in Figure 4-3 above. Though this special zone is encompassed by the NA90(1) contour, it has been primarily developed as residential to date, and is not suitable for commercial or industrial development, because nonresidential uses are not be compatible with local water quality objectives in this area. There is a further concern that nonresidential development could significantly diminish the desirability and value of the existing residential development. Therefore, the City has determined that the only viable future development option in Zone 1A is residential use.

The primary measure recommended within Overlay Zone 1A is to require that landowners and developers grant avigation easements for new residential development similar to Overlay Zone 2. A requirement that new noise sensitive development achieve an outside to inside noise level reduction of at least 30 dB, including sufficient ventilation and central air conditioning to allow for windows closed conditions year round, is also recommended in this Zone. As in all other overlay zones, Wyle recommends that a formal written disclosure of over-flight noise exposure levels be required as a part of all real estate transfer transactions, regardless of the underlying land use.

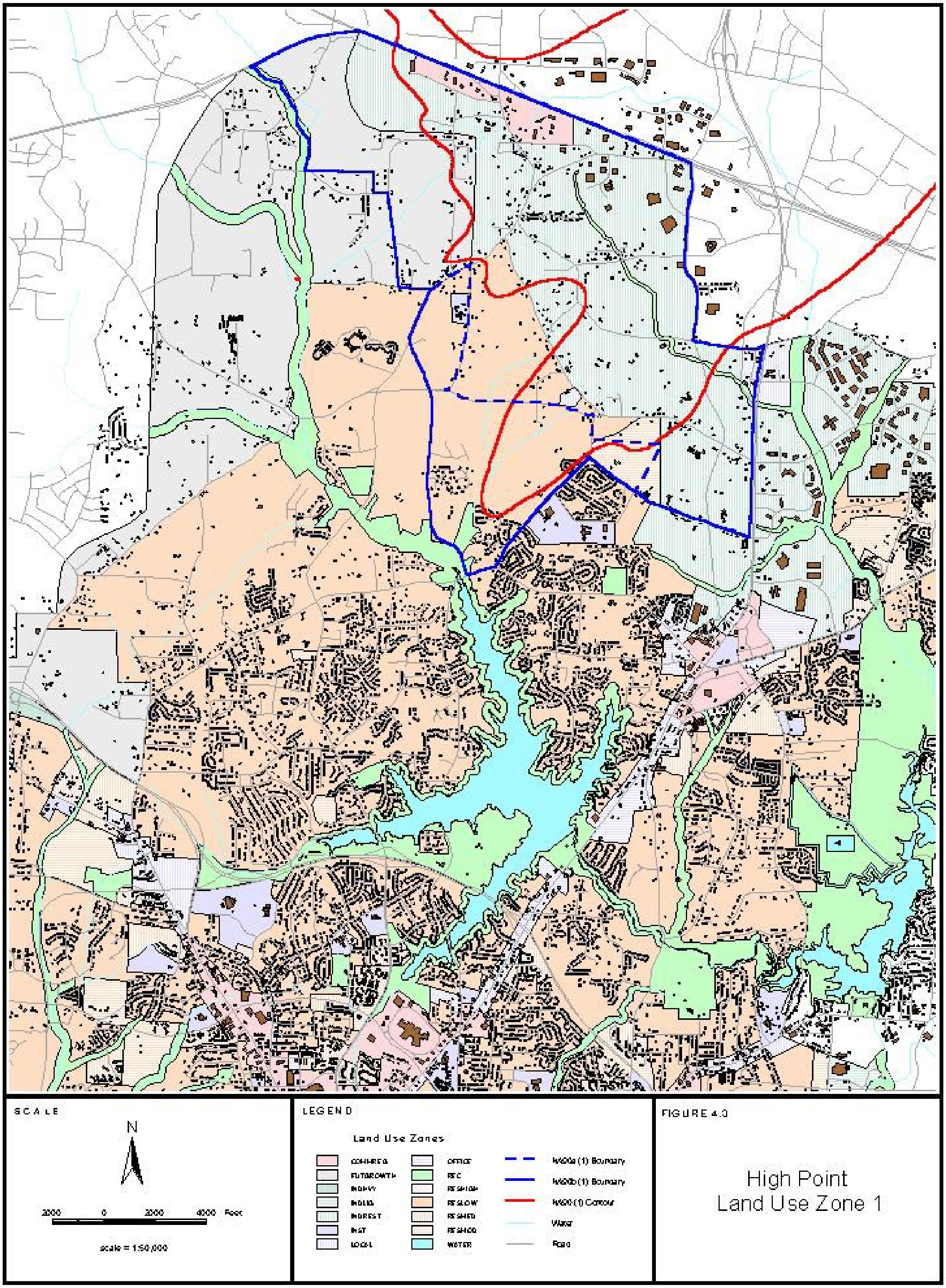


FIGURE 4.3

High Point
Land Use Zone 1

APPENDIX A

Discussion of Noise

Noise, often defined as unwanted sound, is one of the most common environmental issues associated with aircraft operations. Of course, aircraft are not the only sources of noise in an urban or suburban surrounding, where interstate and local roadway traffic, rail, industrial, and neighborhood sources also intrude on the everyday quality of life. Nevertheless, aircraft are readily identifiable to those affected by their noise and are typically singled out for special attention and criticism. Consequently, aircraft noise problems often dominate analyses of environmental impacts.

Sound is a physical phenomenon consisting of minute vibrations which travel through a medium, such as air, and are sensed by the human ear. Whether that sound is interpreted as pleasant (for example, music) or unpleasant (for example, aircraft noise) depends largely on the listener's current activity, past experience, and attitude toward the source of that sound. It is often true that one person's music is another person's noise.

The measurement and human perception of sound involves two basic physical characteristics _ intensity and frequency. Intensity is a measure of the acoustic energy of the sound vibrations and is expressed in terms of sound pressure. The higher the sound pressure, the more energy carried by the sound and the louder the perception of that sound. The second important physical characteristic is sound frequency which is the number of times per second the air vibrates or oscillates. Low-frequency sounds are characterized as rumbles or roars, while high-frequency sounds are typified by sirens or screeches.

The loudest sounds which can be detected comfortably by the human ear have intensities which are 1,000,000,000,000 times larger than those of sounds which can just be detected. Because of this vast range, any attempt to represent the intensity of sound using a linear scale becomes very unwieldy. As a result, a logarithmic unit known as the decibel (abbreviated dB) is used to represent the intensity of a sound. Such a representation is called a sound level.

A sound level of 0 dB is approximately the threshold of human hearing and is barely audible under extremely quiet listening conditions. Normal speech has a sound level of approximately 60 dB. Sound levels above about 120 dB begin to be felt inside the human ear as discomfort and eventually pain at still higher levels.

Because of the logarithmic nature of the decibel unit, sound levels cannot be added or subtracted directly and are somewhat cumbersome to handle mathematically. However, some simple rules of thumb are useful in dealing with sound levels. First, if a sound's intensity is doubled, the sound level increases by 3 dB, regardless of the initial sound level. Thus, for example:

60 dB + 60 dB = 63 dB, and

80 dB + 80 dB = 83 dB.

The total sound level produced by two sounds of different levels is usually only slightly more than the higher of the two. For example:

60.0 dB + 70.0 dB = 70.4 dB.

Because the addition of sound levels behaves differently than that of ordinary numbers, such addition is often referred to as "decibel addition" or "energy addition". The latter term arises from the fact that what we are really doing when we add decibel values is first converting each decibel value to its corresponding acoustic energy, then adding the energies using the normal rules of addition, and finally converting the total energy back to its decibel equivalent.

An important facet of decibel addition arises later when the concept of time-average sound levels is introduced to explain Day-Night Average Sound Level. Because of the logarithmic units, the time-average sound level is dominated by the louder levels which occur during the averaging period. As a simple example, consider a sound level which is 100 dB and lasts for 30 seconds, followed by a sound level of 50 dB which also lasts for 30 seconds. The time-average sound level over the total 60-second period is 97 dB, not 75 dB.

The minimum change in the sound level of individual events which an average human ear can detect is about 3 dB. A change in sound level of about 10 dB is usually perceived by the average person as a doubling (or halving) of the sound's loudness, and this relation holds true for loud sounds and for quieter sounds. A decrease in sound level of 10 dB actually represents a 90 percent decrease in sound intensity but only a 50 percent decrease in perceived loudness because of the nonlinear response of the human ear (similar to most human senses).

Sound frequency is measured in terms of cycles per second (cps), or hertz (Hz), which is the preferred scientific unit for cps. The normal human ear can detect sounds which range in frequency from about 20 Hz to about 15,000 Hz. All sounds in this wide range of frequencies, however, are not heard equally well by the human ear, which is most sensitive to frequencies in the 1000 to 4000 Hz range. In measuring community noise, this frequency dependence is taken into account by adjusting the very high and very low frequencies to approximate the human ear's lower sensitivity to those frequencies. This is called "A-weighting" and is commonly used in measurements of community environmental noise.

Sound levels measured using A-weighting are most properly called A-weighted sound levels while sound levels measured without any frequency weighting are most properly called sound levels. However, since most environmental impact analysis documents deal only with A-weighted sound levels, the adjective "A-weighted" is often omitted, and A-weighted sound levels are referred to simply as sound levels. In some instances, the author will indicate that the levels have been A-weighted by using the abbreviation dBA or dB(A), rather than the abbreviation dB, for decibel. As long as the use of A-weighting is understood to be used, there is no difference implied by the terms "sound level" and "A-weighted sound level" or by the units dB, dBA, and dB(A).In this document all sound levels are A-weighted sound levels and the adjective "A-weighted" has been omitted.

Sound levels do not represent instantaneous measurements but rather averages over short periods of time. Two measurement time periods are most common _ one second and one-eighth of a second. A measured sound level averaged over one second is called a slow response sound level; one averaged over one-eighth of a second is called a fast response sound level. Most environmental noise studies use slow response measurements, and the adjective "slow response" is usually omitted. It is easy to understand why the proper descriptor "slow response A-weighted sound level" is usually shortened to "sound level" in environmental impact analysis documents.

APPENDIX B

Annoyance/Sleep Criteria and Research (1974 – to date)

Background on First Criteria

In accordance with the Noise Control Act of 1972, the U.S. Environmental Protection Agency (EPA) developed and published criteria with respect to environmental noise in a 1974 document, commonly referred to as the "Levels Document" (EPA 1974). The purpose of the criteria is to "reflect the scientific knowledge most useful in indicating the kind and extent of all identifiable effect of noise on the public health and welfare which may be expected from differing quantities and qualities of noise". The Levels Document also prescribed that standards and regulations must account not only for the health and welfare considerations described in the criteria, but also for technical and economical feasibility. The term "health and welfare" as used in the Noise Control Act refers to the physical and mental well being of human populations. The term also includes other indirect effects, such as annoyance, interference with communication and sleep, loss of value and utility of property, and effects on other living things (EPA 1973). The noise levels as published in this document are still accepted today as the nationwide benchmark. While no subsequent noise level criteria document has supplanted the EPA Levels Document, many researchers have conducted numerous studies that recommend noise level criteria for annoyance, speech interference, and sleep disturbance.

1.0 Annoyance

Annoyance is a psychosocial response to an auditory experience, which has its roots in the unpleasantness of noise, in the disruption by noise of ongoing activities, and/or in the meaning or message carried by a given noise (EPA 1973). Numerous laboratory studies and field surveys have been devised to measure annoyance to account for all of the variables, which are dependent on each annoyed person's individual circumstances and preferences. Laboratory studies of individual response to noise have helped isolate a number of the factors contributing to annoyance, such as the intensity level and spectral characteristics of the noise, duration, the presence of impulses, pitch, information content, and the degree of interference with activity. Social surveys of community response to noise have allowed the development of general dose-response relationships that can be used to estimate the proportion of people who will be highly annoyed by the noise.

By soliciting responses to the question "how annoyed are you?" these surveys provide an assessment of people's overall reaction to noise, taking into account all of the ways in which it may affect them – interference with speech or sleep, recreation, watching television, etc. The surveys have revealed that the level of annoyance depends on a host of factors, such as:

- A person's general sensitivity to noise,
- Feelings about the necessity of the noise and the presence of the highway/airport,
- Fear associated with the activities of the noise source, such as fear of aircraft crashes,
- The extent to which the community believes that the noise source could be controlled, and whether authorities are attempting to mitigate the noise.

To date, there are no annoyance criteria that take into account all the identified factors associated with aircraft noise and the community response. Depending on area specific demographics, among other factors, the annoyance will vary. From a cost and feasibility standpoint only an average quantification can be justified, since it is generally impossible to conduct detailed annoyance studies for each area exposed to aircraft noise. As such, the EPA's (1974) "Levels Document" identifies an outdoor DNL of 55 dB and an indoor DNL of 45 dB as the levels below which the vast majority of the population will not register any annoyance. These levels are not to be construed as standards and do not represent discrete numbers as they are described in terms of energy equivalents. EPA also states that "A noise environment not annoying some percentage of the population cannot be identified at the present time by specifying a noise level alone" (EPA, 1974, p. D-36).

In the early 1970s a number of social surveys were conducted to document the magnitude of noise pollution and the community reactions due to transportation noise. Community annoyance due to environmental noise, whether from aircraft, railroad, or highway traffic was the focus of these social surveys. Eleven of such social surveys showed much similarity and were included in what is commonly referred to as the 'Schultz Curve' (Schultz, 1978). The Schultz curve indicates the percentage of the population that might be highly annoyed at different levels of noise (DNL), and at the time was considered the best available instrument to predict community annoyance due to transportation noise of all kinds. Of the eleven social survey results that were included in Schultz's analyses, seven were specifically related to aircraft noise. Figure 1-1 illustrates the Schultz curve and its 90% incidence corridor. The Schultz curve is widely used for land-use planning criteria in the U.S. Figure 1-1 illustrates that a DNL of 65 dB corresponds to approximately 15% Highly Annoyed people. The EPA's outdoor DNL of 55 dB 'below which the vast majority of the population will not register any annoyance' corresponds to approximately 5% of the population that will be Highly Annoyed according to the Schultz curve.

The ''level of significance for assessing noise impacts" as identified by the FAA is a DNL of 65 dB. This is the level that has to be exceeded for noise mitigation funds to be dispensed by the FAA (2000). Similar to the FAA, the DoD also adopted 65 dB as the noise level criteria, and 'air installation compatibility use zone studies" (the equivalent of civil aviation's Part 150 studies) need to depict this contour at a minimum (DoD 1994).

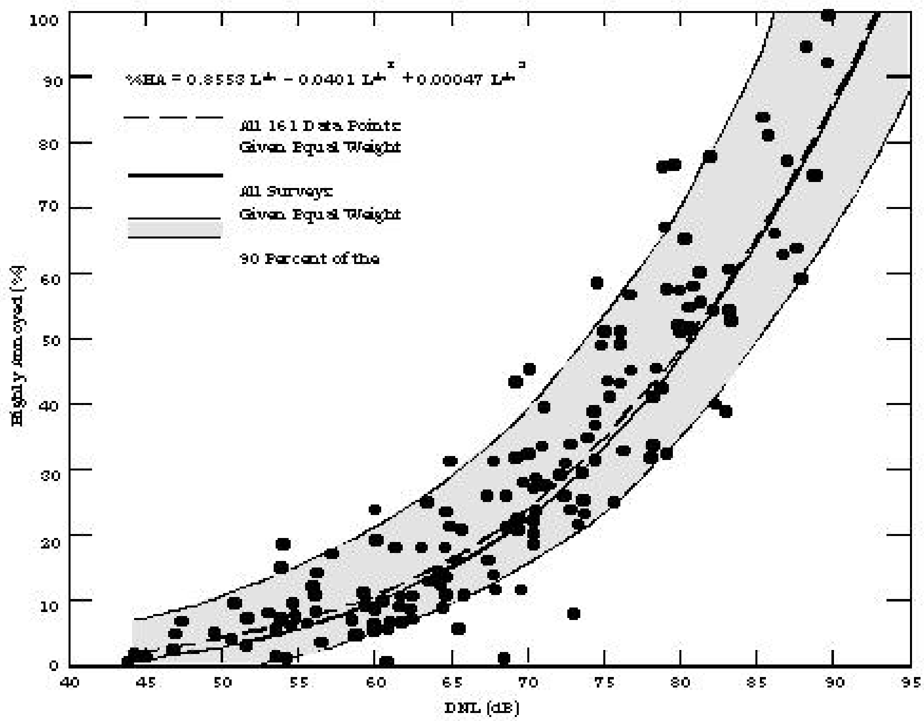


Figure A-2. Community Surveys of Noise Annoyance
(Reference A6.)

Figure 1-1. Schultz Curve – Outdoor DNL Versus Percentage Highly Annoyed

One of the variables that has been studied is the degree of annoyance associated with the source of the noise. Depending on the source, the annoyance of individuals might be unjustifiably influenced. Miedema & Vos (1998) present synthesis curves for the relationship between DNL and percentage 'Annoyed' and percentage 'Highly Annoyed' for three transportation-noise sources. Separate, non-identical curves were found for aircraft, road traffic, and railway noise. These curves show a higher percentage of the exposed population to be annoyed or highly annoyed when the source of the noise is aircraft (Miedema, 2002). Figure 1-2 illustrates that for a DNL of 65 dB the percent of the people forecasted to be Highly Annoyed, is 28% for air traffic, 16% for road traffic, and 9% for railroad traffic. For an outdoor DNL of 55 dB the percentage highly annoyed would be close to 10 % and for a DNL of 50 dB close to 5% if these levels are generated by aircraft operations, but only 5 % and 3% respectively were the source generated by road traffic.

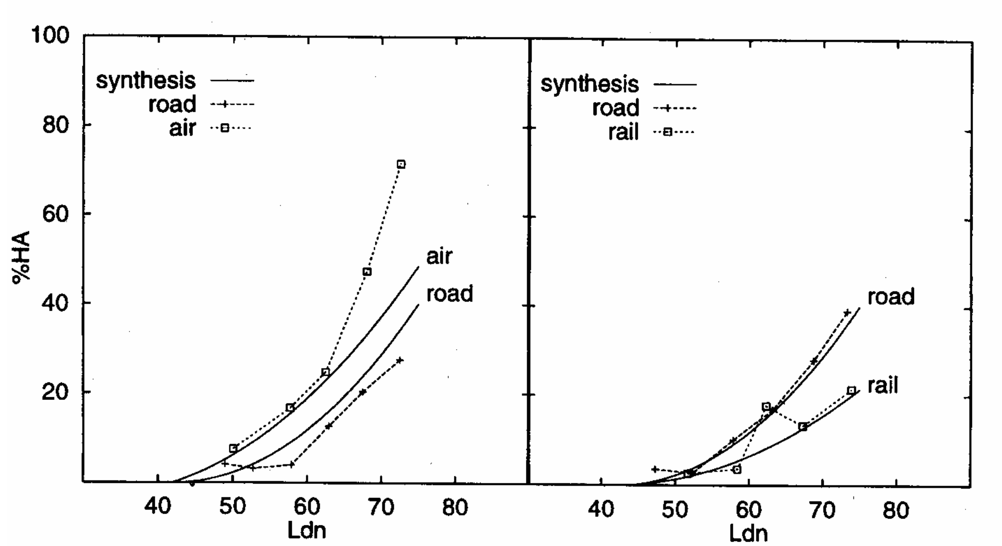


Figure 1-2. Miedema's Annoyance Curves for Three Transportation Noise Sources Indicating Percentage Highly Annoyed Exposed Population

Comparing the levels on Miedema's curve to those on the Schultz curve indicates that the percentage of highly annoyed people is higher when the source of the noise is solely generated by aircraft activity. Miedema concludes that these curves can be used to establish noise limits, and they can be used to compare plans with respect to the noise impact on the community (1998).

Considering all the previous studies regarding annoyance caused by environmental noise, the World Health Organization (WHO) recommends the following levels in the Community Noise Document (WHO, 1999):

- Few people are "moderately annoyed", when the average outdoor daytime/evening noise level, $Leq_{(16)}$, does not exceed 50 dB, and
- Few people are "seriously annoyed", when the average outdoor daytime/evening noise level, $Leq_{(16)}$, does not exceed 55 dB.

Assuming that "seriously annoyed" as defined by the WHO is roughly equivalent to 'Highly Annoyed' as identified by Schultz and Miedema, WHO's criteria of 55 dB at which few people are seriously annoyed, corresponds to 5 % on the Schultz highly-annoyed curve, and 10% on Miedema's air traffic highly annoyed curve. WHO (1999) also states that the maximum noise levels as well as the number of noise events should be taken into account when attempting to quantify intermittent noise such as that from aircraft operations. Table 1.1 summarizes the annoyance criteria described above.

Table 1-1. Annoyance Noise Level Criteria Summary

Metric/Level (dB) /outdoor (o)	Source	Effects and Notes
DNL 55 (o)	EPA 'Levels Document"	No average community reaction 1% may complain 17% may be annoyed
DNL 65 (o) DNL 55 (o)	Shultz Curve	15% HA, (FAA and DOD criteria) 5% HA
DNL 65 (o) DNL 55 (o) DNL 50 (o)	Miedema	HA % for Air/Road/Rail: 28/16/9 HA % for Air/Road/Rail: 10/5/3 HA % for Air/Road/Rail: 5/3/2
$Leq_{(16)}$ 55 (o) $Leq_{(16)}$ 50 (o)	WHO	few Seriously Annoyed few Moderately Annoyed

Annoyance is generally the by-product of interference with some activity, whether it is speech, listening to television or radio, or sleep. Annoyance alone is not an accurate measure for environmental noise effects, but that the individual components that create potential annoyance should be analyzed. In order to further evaluate the degree of annoyance, the interference with specific activities needs to be evaluated.

2.0 Sleep Disturbance

Disturbance of sleep is a major concern in the assessment of environmental noise levels a good night's sleep is essential to a person's physiological health and well-being. Physiological effects, such as increased blood pressure and heart rate, can result from exposure to noise during sleep. However, the major manifestations of noise are to delay the onset of sleep, to change the depth of sleep (from one stage to another), and at most, to actually awaken. The relationships between noise levels and the magnitude of any of these effects are rather complex because the disturbance caused by an intruding sound can depend on the background noise level, the depth of sleep, previous exposure to aircraft noise, familiarity with the surroundings, the physiological and psychological condition of the recipient, and a host of other situational factors. The most readily measurable effect of noise on a sleeping person is the number of arousals or awakenings, and these are the effects for which current relationships are based.

2.1 Laboratory Sleep Research Findings

As previously mentioned the EPA levels document of 1974 was the cornerstone for noise level criteria in the U.S. One of the studies included in the compilation of these levels indicated that at least 48 percent of people exposed to aircraft noise were extremely disturbed during conversation or listing to the radio or television. Only 8 percent however, claimed that the aircraft noise extremely disturbed their sleep in this particular study (pg. D-13). This indicated that interference with speech and listening was a larger concern than sleep disturbance at that time, and the EPA levels document does not explicitly provide a sleep disturbance criteria.

The effect of intermittent or time-varying noise (i.e. aircraft fly-overs) on sleep is best described in terms of the SEL or the L_{max} of individual events. A number of studies have attempted to quantify the noise levels that interfere with sleep since the early 1960s. In the earlier years, field studies conducted with people in their normal living situations were scarce. Consequently much of the data on the impact of noise exposure on sleep originated primarily from experimental research in controlled laboratory environments. Until the late 1980s and early 1990s, the results of these laboratory experiments were used as a benchmark for establishing acceptable noise levels with the least amount of sleep disturbance. In 1992, the Federal Interagency Committee on Noise (FICON) recommended a dose-response curve, which predicted the percent of the exposed population expected to be awakened (% awakening) as a function of the exposure to single event noise levels expressed in SEL. This curve incorporated most of the research performed up to that point, and indicated that 10% of the population was predicted to be awakened when exposed to an SEL of approximately 58 dB (FICON, 1992), illustrated in Figure 2-1. The data utilized to derive this relationship was primarily the result of the many laboratory studies performed up till that time.

2.2 Field Test Sleep Disturbance Findings

It was noted in related research that the controlled laboratory studies did not account for many factors that are important when analyzing sleep behavior, such as habituation to the environment, previous exposure to noise, awakenings from sources other than aircraft noise, etc. In the early 1990s, field studies were conducted to validate the earlier laboratory work. The most significant finding from these studies was that an estimated 80 to 90 percent of sleep disturbances were not related to individual outdoor noise events, but were instead the result of indoor noises and other non-noise-related factors (Reyner & Horne, 1995). Moreover, it was found that there was a distinctly lower effect of noise on sleep in real-life conditions than had been previously reported from laboratory studies (Pearsons, 1995). A study performed in 1992 by the Civil Aviation Policy Directorate of the Department of Transportation in the U.K. concluded that average sleep disturbance rates are unlikely to be effected by aircraft noise for outdoor levels below an L_{max} of 80 dB (Ollerhead, 1992).

Based on the findings of higher levels and less impact on the population from field studies, the Federal Interagency Committee on Aviation Noise (FICAN) updated its recommended dose-response curve in 1997. The new relationship represents the upper envelope of the latest field data, and should be interpreted as predicting the "maximum percent of the exposed population expected to be behaviorally awakened" or the "maximum % awakened" for a given residential population (FICAN, 1997). According to this relationship, a maximum of 3 percent of people would be awakened at an indoor SEL of 58 dB (compare to 10 percent using the 1992 curve). This correlation between SEL and percent awakenings does not take into account the number of occurrences or the duration of each occurrence.

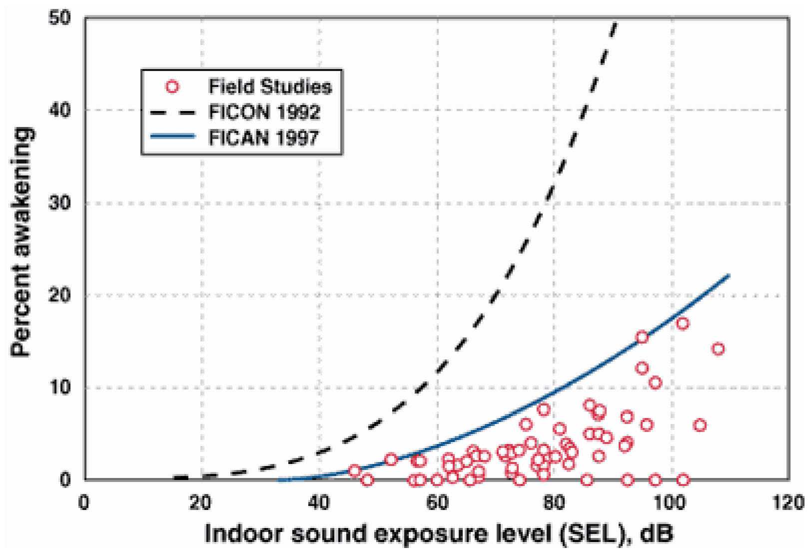


Figure 2-1. Recommended Sleep Disturbance Dose-Response Relationship

Similar to the FICAN 1997 curve, Fidell et al. (2000) generated a curve to identify the sound levels that cause awakenings based on several field studies including Ollerhead's 1992 U.K study and Fidell et. al's 1995 Denver airport, deKalb Peachtree airport, and Castle Air Force Base studies. Figure 2-2 illustrates the resultant curve fit of the data point from the field studies related to awakenings. These are primarily the studies that were incorporated into the new FICAN curve, however as mentioned earlier, the modified FICAN awakenings curve only represents the upper envelope of the field data.

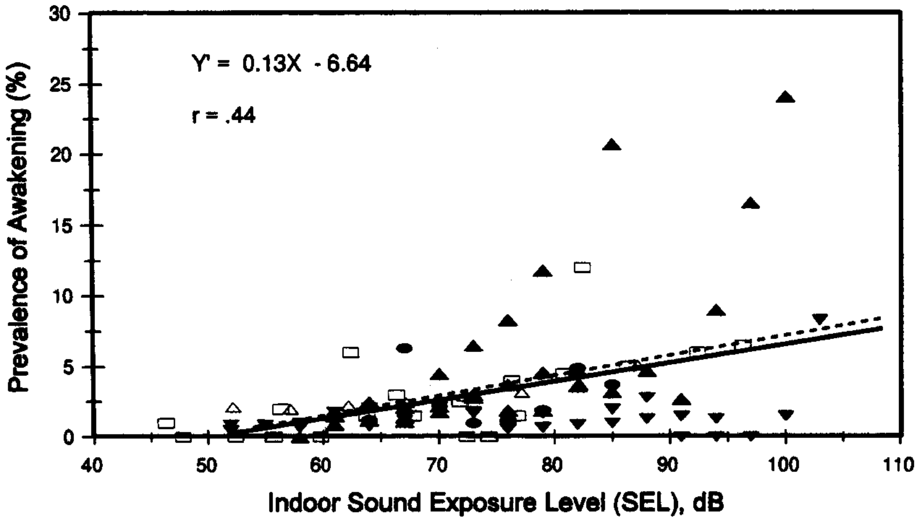


Figure 2-2. Fidell et al. Indoor SEL versus Prevalence of Awakenings Curve Based on Field Studies Alone

This curve indicates that even fewer people are awakened than the FICAN 1997 curve indicates. An indoor SEL of 58 dB using Fidell's curve in Figure 2-2, corresponds to approximately 2 percent of the population who will be awakened, versus 3 and 10 percent for the same level on the FICAN 1997, and 1992 curves respectively. This supports statements by Schultz (1978) "Aircraft noise interferes more with speech than with sleep" and explains the response of many survey participants that answered "How would I know, I was asleep" when asked if they noticed a decrease in night time noise events over LAX during a field study (Fidell 1975).

The WHO (1999) concluded that high sound levels created by both continuous and intermittent noise indoors leads to sleep disturbance. Prior research indicates effects at individual L_{max} exposures of 45 dB or less. When the disturbing noise is fairly continuous, as may be the case with noise from air conditioning systems or steady highway traffic flow, it is appropriate to define its magnitude in terms of the long-term average noise level, Leq. The WHO recommends an indoor threshold long-term average noise level, Leq, of 30 dB to avoid sleep disturbance, but emphasize that proper use of the guideline suggests the use of both the intermittent and continuous noise criteria.

2.3 Noise level and Number of events

Other studies indicated that for a good sleep, not only the noise level but also the number of occurrences plays a role. Vallet & Vernet (1991) recommend that indoor noise levels should not exceed approximately 45 dB L_{max} more than 10–15 times per night to avoid any adverse effects on sleep and that lower levels might be appropriate to provide protection for sensitive people. This L_{max} level is equivalent to an SEL of approximately 55 dB indoors, and 70 dB outdoors, with open windows.

In the recently published TNO Inro Report 2002-59, Miedema uses L_{night} as the metric to describe the long-term incidence of instantaneous effects. L_{night} (or Leq_9) is the sum of the individual sound exposure levels during that night divided by the duration of the night, and can be simplified into the equation:

$$L_{night} = SEL + 10\log N - 10\log(t)$$

Where 'N' is the number of events with the SEL value, and 't' is the duration of the night in seconds. Using an L_{night} of 45 dB and SELs of 90 dB, 85 dB, and 80 dB in this equation results in 1, 3, and 10 number of events, respectively.

This paper also presents the increase in mean motility (movement) as a function of the outdoor L_{night} for nighttime aircraft noise events. This results in percentage highly sleep disturbed (%HSD), sleep disturbed (%SD), and a little sleep disturbed (%LSD) people, due to road traffic or railway noise. Using the relationships described in this report, an L_{night} of 45 dB results in 1.9 and 3.6 %HSD people from railroad and traffic noise respectively.

The report indicates that the sleep disturbance identifiers do not include aircraft noise sources. In previous analyses Miedema derived percent Highly Annoyed (%HA) as a function of various transportation noise sources. Table 1.1 in the Annoyance section indicates that at DNL values of 50, 55, and 65 dB, the %HA due to aircraft noise is 1.7 to 2 times higher than %HA due to road noise. Assuming that aircraft noise is equally more disturbing to sleep than road noise, as indicated in Table 1.1, an L_{night} of 45 dB could approximate to 7 %HSD due to aircraft noise. It has to be noted that this percentage is derived from a relationship between aircraft and road response in terms of %HA. Annoyance in general is a descriptor for the overall reaction to noise, including not only sleep disturbance, but also interference with speech, recreation, watching television, and multiple other activities. As sleep disturbance is only one of many activities that cause annoyance the relationship between aircraft and road noise for %HSD as derived above may very well by much lower than that for %HA.

Table 2.1 summarizes the levels as recommended or as resulting from the research and literature discussed above. As some criteria were discussed in varying metrics all levels in this table were converted to an outdoor SEL for comparison. Assumptions were that the noise level difference from indoor to outdoor with windows open is 15 dB and the difference from L_{max} to SEL is 10 dB.

Table 2-1. Sleep Disturbance Noise Level Criteria Summary

Metric/Level (dB)/outdoor (o)	**Source**	**Effects and Notes**	**Conversion**
SEL 56(i)	FICAN (1992)	10 % Awakenings Primarily based on laboratory studies	SEL 71 (o)
SEL 80 (i) SEL 56 (i)	FICAN (1997)	10 % awakenings 3 % awakenings Average of lab and field studies	SEL 95 (o) SEL 71 (o)
SEL 92 (i) SEL 56 (i)	Fidell, et al. (2000)	5 % prevalence of awakenings 2 % prevalence of awakenings Combination of field studies	SEL 107 (o) SEL 71 (o)
L_{max} 80 (o)	Ollerhead (1992)	Probability of minor arousal = 1 in 30 Probability of brief awakening = 1 in 75	SEL 90 (o)
Leq 30 (i) L_{max} (i) 45	WHO (1999)	No Awakenings - Continuous noise No Awakenings - Intermittent noise	 SEL 70 (o)
L_{max} 45 (i)	Vallet & Vernet (1991)	For good sleep don't exceed level 10-15 times a night	SEL 70 (o)

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